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Agenda item [[2]](#footnote-2) 7.3

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Decision-making for the autonomous navigation of MASS in port

# Summary

It is extremely challenging to carry out an advanced adaptive navigation system in the complex environment of a port. Especially in the waters to be berthed, the maritime automatic surface ship (MASS) should autonomously identify and avoid dense buoys according to the rules.

According to the existing situation of MASS guide compilation, the navigation decision-making research of MASS ship is carried out. It is suggested that MASS should reasonably increase the corresponding control decision to avoid collision according to the types of buoys, so that MASS ships can better complete safe navigation according to the indication information of different types of buoys.

## Purpose of the document

MASS should follow the constraints of the IALA (International Association of Marine Aids and Lighthouse Authorities) Maritime buoyage system, to design the decision-making collision avoidance in port environment. Therefore, it is necessary to add manipulate strategies to avoid collision reasonably according to different buoy types, to allow the MASS to better complete safe navigation. Provide reference for the compilation of MASS guidelines.

## Related documents

ARM 18 - Proposed ARM MASS Guideline Apr 24

Proposed Framework for MASS Guidance

# Background

To achieve full intelligence of maritime automatic surface ships (MASSs), it is necessary to complete not only a variety of navigation tasks in the high seas, but also adaptive navigations in ports. And in the entry waters of various countries, some specific types and tonnages of ships are forced to pilot. The primary problem faced by autonomous navigation and collision avoidance is to avoid dangerous areas and navigate to the target position according to the buoy’s instruction rules.

In order to ensure the safe navigation of MASS ships in port, collision avoidance decisions need to be made in conjunction with the IALA buoy system guidelines in the waters of entry. Due to the complexity of port environment, there are the following important problems to be studied and solved:

1. Due to the influence of wind and waves, the position of the indicator buoy in the port map is not static, and the grid-based map modeling becomes inapplicable in practical situations.
2. The traditional collision avoidance rules are to find obstacles and then steer to avoid collisions. However, all kinds of buoys mainly provide indicative information, not only represent dangerous obstacles, so in face of different types of buoys, the traditional collision avoidance rules cannot fully meet the global optimal route.
3. In the entry waters from the anchorage to the wharf, the key to navigation lies in the “safe path”. The distance, consumption and smoothness are not considered here, and it is difficult for traditional algorithms to define the constraints of the “safe path".

In view of the above problems, considering MASS manoeuvring characteristics, IALA Maritime Buoyage System and navigation experience, an autonomous collision avoidance about adding manipulate strategies in port is proposed. Using this algorithm, the MASS can achieve autonomous navigation under the constraints of the IALA Maritime Buoyage System.

# Discussion

## Modeling of autonomous ship

In order to model the dynamics of the autonomous ship, the coordinate system (figure 1) should define series of environmental information as follows:

(1)The Euclidean distance between the ship and the buoy is ⃦ *Pbouy* - *POb* ⃦; (2)the absolute azimuth is θ; (3)the heading angle isψ;(4)the relative azimuth of the buoy is θe= θ-ψ.



Figure 1. The motion model of the ship

## Collision avoidance decision

Autonomous collision avoidance navigation in port waters, the MASS interacts with the environment, uses a variety of equipment to avoid obstacles and discriminate buoys, the goal of the algorithm is that the MASS completes the navigation task under the guidance of the buoy. The MASS regards the buoy as an indicator rather than a single obstacle. It needs to add manipulate strategies to avoid collision reasonably according to different buoy types.

During the voyage, the MASS collects a series of environmental information as follows:

(1)The Euclidean distance between the ship and the buoy is ⃦ *Pbouy* - *POb* ⃦; (2)the absolute azimuth is θ; (3)the heading angle isψ;(4)the relative azimuth of the buoy is θe= θ-ψ.Depending on the types of buoys, the setting objects in the rules will change.

### Decision-making mechanism

MASS must meet the conditions of the buoy rules to successfully reach the target point; Therefore, it is necessary to add manipulate strategies mechanism for each buoy to successfully reach the end point and ensure the safety of the final path.

1. Lateral marks strategy

The lateral mark needs to be judged by the own ship as the object in the rules. The own ship needs to place the sign on the port or starboard side. The azimuth map of the own ship is as shown in the figure 2.



Figure 2 The azimuth map of the own ship

Entering the own ship within 1 nautical mile of lateral marks, that is ⃦ Plateral mark - PO b  ⃦≤ 1 n mile, it needs to give related strategy to the MASS angle about lateral marks:

when , need to increase the manipulate strategy for the port hand mark;

when , need to increase the manipulate strategy for the starboard hand mark.

The closer to the centre of [5◦, 112.5◦] or [247.5◦, 355◦], the greater the manipulate should be.

The function of the recommended channel lateral marks is not to indicate the location of dangerous objects, but to provide recommended waterways for some ships with special draughts. Failure to follow the instructions will not affect navigation safety. It’s assumed as an obstacle to avoid.

1. Cardinal marks strategy

For the cardinal marks, the marker needs to be the setting object, and the ship cannot appear on the north and south sides of the marker. As a sign indicating the direction of the dangerous object, it is necessary to set strategies for the four directions respectively. When the MASS appears within 1 nautical mile of the cardinal mark, that is ⃦ Pcardinal mark - POb  ⃦≤ 1 n mile, the azimuth mark manipulate is added. For the cardinal mark, the strategies are as follows:

when , need to increase the manipulate strategy for the north cardinal mark;

when , need to increase the manipulate strategy for the west cardinal mark;

when or , need to increase the manipulate strategy for the south cardinal mark;

when , need to increase the manipulate strategy for the east cardinal mark.

1. Isolated danger marks strategy

An isolated danger mark indicates the presence of a hazard in its vicinity, but does not indicate a specific position or distance. It’s assumed to be avoided as a larger range of obstacles. When ⃦ Pisolated danger mark - POb  ⃦≤ 1 n mile, the isolated hazard mark strategy is added.

1. Special marks strategy

Special marks are used to indicate a special area or feature whose nature may be apparent from reference to a chart or other nautical publication. They are not generally intended to mark channels or obstructions where the MBS provides suitable alternatives. When ⃦ Pspecial mark - POb ⃦≤ 2 n mile, the special mark strategy is added.

1. The safe water marks strategy

The safe water mark is generally set at the entrance of the port, close to the target point. If the MASS gives priority to approaching the safe water mark when approaching the target point from a long distance, after entering the port, it will deviate from the safe water mark, which will affect the MASS’s autonomous decision-making. It is suggested that the safe water mark is used as the target point, which means that once the MASS collide with it, the voyage will be terminated. Therefore, it is suggested that MASS will only take the decision corresponding to avoiding the safe water mark.

### Collision avoidance decision-making process

In MASS sailing, the strategies of these marks need to be fully considered. A brief flowchart of the collision avoidance decision-making process is shown in figure 3. The MASS relies on equipment’s information to identify obstacles, the ultimate goal of the MASS is to reach the target point without breaking the rules. When it is far from the target point and there is no obstacle ahead, the MASS maintains the heading towards the target point and returns to the correct heading by manoeuvring after yaw. However, in the process of navigating in the port, there will always be obstacles in the MASS’s field of vision. By setting the above strategies for violations of the rules, the MASS prioritizes the types of obstacles ahead, divides them into reefs and buoys, and then continues to classify buoys by their characteristics. However, in the strategies set above, the safe water mark is set as static obstacles of the same type as reefs, so the safe water mark and the IALA buoy system, the safe water mark is different from other buoys. It does not indicate a specific navigable channel, but indicates that the area is not a “fishing area” or “anchorage”, etc. Therefore, it is part of the IALA buoy system and points to the IALA buoy system at the same time as other guidance obstacles.



Figure 3 Flowchart for navigation

The purpose of this proposal, as the first step in autonomous pilotage in port, is to allow the MASS to better complete safe navigation according to different types of buoy indication information. The second key issue that needs to be studied in port pilotage is the calculation of reef height. Pilots in each port are fully aware of the location of each reef in the port and can use tide tables and current time to calculate a new safe path. Then it is need to add the reef to the environmental information and the MASS can calculate the height of the reef autonomously.

# References

None

# Action requested of the Committee

The Committee is requested to:

1. note the work carried out by China MSA in respect of Maritime Autonomous Surface Ship (MASS) and the interaction between MASS and navigation mark, namely, identify the buoys and make the decisions as proposed in this document.
2. consider the practicability of incorporating the mentioned and incorporate relevant recommendations into IALA's Guidance on Maritime Autonomous Surface Ship (MASS).

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)